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PATENT APPLICATION
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First Named Inventor or Application Identifier

Yonatan Aharon Levy et al.

Express Mail Label No.

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APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

ADDRESS TO:

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1. ☒ Fee Transmittal Form
(submit an original, and a duplicate for fee processing)
2. ☒ Specification [Total Pages 27]
(preferred arrangement set forth below)
- Descriptive title of invention
 - Cross References to Related Applications
 - Statement Regarding Fed sponsored R&D
 - Reference to Microfiche Appendix
 - Background of the Invention
 - Brief Summary of the Invention
 - Brief Description of the Drawings(if filed)
 - Detailed Description
 - Claim(s)
 - Abstract of the Disclosure
3. ☒ Drawing(s)(35 USC 113) [Total Sheets 4]
4. Oath or Declaration [Total Pages 4]
- a. ☐ Newly executed (original or copy)
- b. ☐ Copy from a prior application(37 CFR 1.63(d))
(for continuation/divisional with Box 17 completed)
[Note Box 5 below]
- i. ☐ DELETION OF INVENTOR(S)
Signed statement attached deleting inventor(s)
named in the prior application, see 37 CFR
163(d)(2) and 1.33(b)
5. Incorporation by reference(useable if Box 4b is checked)
The entire disclosure of the prior application, from which a copy of the oath
or declaration is supplied under Box 4b, is considered as being part of the
disclosure of the accompanying application and is hereby incorporated by
reference herein.

6. ☐ Microfiche Computer Program (Appendix)
7. ☐ Nucleotide and/or Amino Acid Sequence Submission
(if applicable, all necessary)
- a. ☐ Computer Readable Copy
- b. ☐ Paper Copy(identical to computer copy)
- c. ☐ Statement verifying identity of above copies

ACCOMPANYING APPLICATION PARTS

8. ☒ Assignment Papers(cover sheet & document(s))
9. ☐ 37 CFR 3.73(b)Statement ☐ Power of Attorney
10. ☐ English Translation Document (if applicable)
11. ☐ Information Disclosure ☐ Copies of IDS
Statement(IDS)/PTO-1449 Citations
12. ☐ Preliminary Amendment
13. ☒ Return Receipt Postcard (MPEP 503)
(Should be specifically itemized)
14. ☐ Small Entity ☐ Statement filed in prior application,
Statement(s) Status still proper and desired
15. ☐ Certified Copy of Priority Document(s)
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16. ☐ Other :

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☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior Application No:

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or ☒ Correspondence address below

NAME	Samuel H. Dworetzky				
ADDRESS	AT&T CORP. P.O. Box 4110				
CITY	Middletown	STATE	New Jersey	ZIP CODE	07748-4110
COUNTRY	United States of America			FAX	732-368-6932

19. SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT REQUIRED

NAME	Susan E. McGahan	Reg. #	35948
TELEPHONE	908-221-5776		
SIGNATURE	<i>Susan E. McGahan</i>		
DATE	Nov. 27, 2000		

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I hereby certify that this application is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to the Commissioner for Patents, Washington D.C. , 20231

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Nicole Barrett

(Signature of Person Mailing Paper)

FEES TRANSMITTAL

Patent Fees are subject to annual revision on October 1.

These are the fees effective October 1, 1997

Small Entity payments must be supported by a small entity Statement, otherwise, large entity fees must be paid. See Forms PTO/SB/09-12.

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Yonatan Aharon Levy et al.

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METHOD OF PAYMENT (check one)

1. The Commissioner is hereby authorized to charge indicated fees and credit any overpayments to:

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Deposit Account Name AT&T CORP.☒ Charge Any Additional Fee Required Under 37 CFR 1.16 and 1.17 ☐ Charge the Issue Fee Set in 37 CFR 1.18 at the Mailing Date of the Notice of Allowance2. ☐ Payment Enclosed☐ Check ☐ Money Order ☐ Other

FEE CALCULATION

1. FILING FEE

Large Fee Code	Entity Fee(\$)	Fee Description	Fee Paid
101	710	Utility Filing Fee	\$710.00
106	320	Design Filing Fee	
107	480	Plant Filing Fee	
108	710	Reissue Filing Fee	
114	150	Provisional Filing Fee	

SUBTOTAL (1) \$710.00

2. CLAIMS

☐ New Filing☐ Amendment

			Extra Claims		Fee from below		Fee Paid
Total	20	- 20=		X	18	=	\$0.00
Ind.	4	- 3=	1	X	80	=	\$80.00
Multiple Dependent Claims			0			=	\$0.00

Large Fee Code	Entity Fee(\$)	Fee Description
103	18	Claims in excess of 20
102	80	Independent Claims in excess of 3
104	270	Multiple Dependent Claims
109	80	Reissue independent claims over original patent
110	18	Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) \$80.00

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Fee Code	Entity Fee(\$)	Fee Description	Fee Paid
105	130	Surcharge - late filing fee or oath	
127	50	Surcharge - late provisional filing fee or cover sheet	
139	130	Non-English specification	
147	2520	For filing a request for reexamination	
112	920*	Requesting publication of SIR prior to Examiner action	
113	1840*	Requesting publication of SIR after to Examiner action	
115	110	Extension for reply within first month	
116	390	Extension for reply within second month	
117	890	Extension for reply within third month	
118	1390	Extension for reply within fourth month	
128	1890	Extension for reply within fifth month	
119	310	Notice of Appeal	
120	310	Filing a brief in support of an appeal	
121	270	Request for oral hearing	
138	1510	Petition to institute a public use proceeding	
140	110	Petition to revive - unavoidable	
141	1240	Petition to revive - unintentional	
142	1240	Utility issue fee (or reissue)	
143	440	Design issue fee	
144	580	Plant issue fee	
122	130	Petitions to the Commissioner	
123	50	Petitions related to provisional applications	
126	240	Submission of Information Disclosure Statement	
581	40	Recording each patent assignment per property(times number of properties)	
146	710	Filing a submission after final rejection(37 CFR 1.129(a))	
149	710	For each additional invention to be examined (37 CFR 1.129(b))	

Other fee (specify)

Other fee (specify)

* Reduced by Basic Filing Fee Paid

SUBTOTAL (3)

SUBMITTED BY

Typed or Printed Name Susan E. McGahan

Complete (if applicable)

Reg. Number 35948

Signature

Date

11/27/2000

Deposit Account User ID

METHOD AND DEVICE FOR EFFICIENT BANDWIDTH MANAGEMENT

Field of the Invention

The present invention relates generally to bandwidth management, and more particularly to dynamic, real-time bandwidth management of traffic in Internet Protocol networks.

Background of the Invention

Today's Internet Protocol (IP) networks mostly work as one-class, best-effort networks. As these networks evolve to Quality of Service (QoS)-enabled, multi-class, application-aware networks, bandwidth management will be one of the crucial resource management mechanisms to insure each application a fair share of bandwidth, especially at congestion points. There are several products, called bandwidth managers or packet shapers, that offer such a mechanism at the access points to or from the Wide Area Network (WAN). In particular, one such scheme, Class Based Queuing (CBQ), has gained significant popularity after being implemented in real bandwidth management products such as Xedia's Access Point® to guarantee bandwidth for applications and provide Quality of Service differentiation. Products offering CBQ are widely available and are being deployed in the field to guarantee bandwidth for real-time and other business-critical applications (e.g., voice, e-transactions). However, a challenging problem in putting these products into practical use is the need to configure them in a way that will match the needs of the particular site and links, whose bandwidth is allocated. There is a need for a method and device that dynamically provide real-time allocation of bandwidth for real-time and non-real-time applications based on

measurements, thus enabling the use of bandwidth managers without the administrative burden of manual configuration and update.

Summary of the Invention

The present invention provides a method for dynamically managing allocation of bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ). The method includes the steps of maintaining a minimized reserved portion of bandwidth to minimize delay jitter and maximizing a shared portion of bandwidth to maximize overall bandwidth utilization. Allocation of bandwidth may be based on a hierarchical-tree sharing scheme that provides for temporary borrowing of bandwidth by real-time or critical applications from bandwidth of non-real-time or non-critical applications and prevents borrowing of bandwidth by non-real-time or non-critical applications from bandwidth of real-time or critical applications. The DSS provides for using measurable parameters, such as queue length or number of borrowing attempts per a predetermined length of time, as control triggers for implementing adjustment of bandwidth allocation.

The present invention may also provide for dynamically managing allocation of bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ) using the steps of measuring a predetermined parameter at predetermined observation window times and dynamically adjusting allocated bandwidth for parent classes of real-time or critical traffic by adjusting an average of the predetermined parameter to have a value within a predetermined stable region. Again, dynamically adjusting allocated bandwidth, such as the DDS method of the present

invention, may be based on a sharing tree hierarchical scheme that provides for temporary borrowing of bandwidth by real-time or critical applications from bandwidth of non-real-time or non-critical applications and blocks borrowing of bandwidth by non-real-time or non-critical applications from bandwidth of real-time or critical applications. The predetermined parameter measured may, for example, be queue length or number of borrowing attempts during a predetermined measurement window. Where the predetermined parameter is a number of borrowing attempts during a measurement window, a maximum bandwidth and a minimum bandwidth for the predetermined stable region may be determined by the following algorithm, where the subscript i stands for class i:

$$\text{If } A_{i_avg} < Thr(A_i)^{lower}, B_i = \text{maximum}(B_i - \omega_i^{down}, \text{Min}(B_i))$$

$$\text{Else If } A_{i_avg} > Thr(A_i)^{upper}, B_i = \text{minimum}(B_i + \omega_i^{up}, \text{Max}(B_i))$$

where A_i is a number of borrowing attempts by class i during a most recent measurement window and

A_{i_avg} is an average number of borrowing attempts/controlled state;

upper and lower thresholds for the predetermined stable region are preset at predetermined values:

$Thr(A_i)^{lower}$ is a lower threshold for borrowing attempts, where $Thr(A_i)^{lower} > 0$;

$Thr(A_i)^{upper}$ is a upper threshold for borrowing attempts, where $Thr(A_i)^{upper} > Thr(A_i)^{lower}$;

the increment and decrement units ω_i^{down} and ω_i^{up} , which denote the update granularity on allocated bandwidth B_i , are preset at predetermined values;

$\text{Max}(B_i)$ is a maximum value of allocated bandwidth;

$\text{Min}(B_i)$ is a minimum value of allocated bandwidth; and

exponential smoothing technique is used as follows,

$$A_{i_avg} \leftarrow (1-\alpha)*A_{i_avg} + \alpha*A_i,$$

where a value of α is preselected as a negative power of two and A_{i_avg} is updated every observation window, a pre-determined parameter in seconds.

Where the predetermined parameter is a queue length, a lower threshold and an upper threshold for queue length for the predetermined stable region may be determined by:

$$\text{If } Q_{i_avg} < Thr(Q_i)^{lower}, B_i = \text{maximum}(B_i - \omega_i, \text{Min}(B_i))$$

$$\text{Else If } Q_{i_avg} > Thr(Q_i)^{upper}, B_i = \text{minimum}(B_i + \omega_i, \text{Max}(B_i)),$$

Q_i is an instantaneous measurement of queue length;

Q_{i_avg} is a calculated average value for an average queue length;

upper and lower thresholds are preset at predetermined values:

$Thr(Q_i)^{lower}$ is a lower threshold for queue length, where $Thr(Q_i)^{lower} > 0$; and

$Thr(Q_i)^{upper}$ is an upper threshold for queue length where $Thr(Q_i)^{upper} > Thr(Q_i)^{lower}$.

The queue size for class i , which is also the upper bound for the queue length Q_i , is related to an upper bound on the delay jitter as:

$$\text{Delay_jitter_}i = \max Q_i / B_i$$

Hence, if a jitter upper bound $\text{Delay_jitter_}i$ is preselected, then a linear relationship exists between $\max Q_i$ and B_i , the allocated bandwidth.

The present invention may also be implemented by a computer-readable medium having computer-executable instructions for dynamically managing allocation of

bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ). The computer-executable instructions may include measuring a predetermined parameter at predetermined observation window times and dynamically adjusting allocated bandwidth for parent classes of real-time or critical traffic by adjusting an average of the predetermined parameter to have a value within a predetermined stable region.

The present invention may be implemented by a device that includes a parameter measuring unit and a bandwidth sharing determining unit. The parameter measuring unit is coupled to the bandwidth sharing determining unit and is used for (i) measuring a predetermined parameter at predetermined observation window times, and (ii) dynamically adjusting allocated bandwidth for parent classes of real-time or critical traffic by adjusting an average of the predetermined parameter to have a value within a predetermined stable region. The DSS generally provides for using measurable parameters such as queue length or number of borrowing attempts per a predetermined length of time or predetermined measurement window as control triggers for implementing adjustment of bandwidth allocation. Where the predetermined parameter is a number of borrowing attempts during a measurement window of the DDS method, a maximum bandwidth and a minimum bandwidth for the predetermined stable region may be determined as described above. Where the predetermined parameter is a queue length of the DDS method, a lower threshold and an upper threshold for queue length for the predetermined stable region may be determined as described above.

Brief Description of the Drawings

The foregoing summary of the invention, as well as the following detailed description of preferred embodiments, is better understood when read in conjunction with the accompanying drawings, which are included by way of example, and not by way of limitation with regard to the claimed invention.

Figure 1 is a schematic representation of a sharing tree hierarchy with three control states generated using limits and thresholds in accordance with the present invention.

Figure 2 is a flow chart showing steps for one embodiment of a method for dynamically managing allocation of bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ) in accordance with the present invention.

Figure 3 is a flow chart and block diagram showing another embodiment of steps of a method and of a computer-readable medium for dynamically managing allocation of bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ) in accordance with the present invention.

Figure 4 is a block diagram showing one embodiment of a device for dynamically managing allocation of bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ) in accordance with the present invention.

Detailed Description of the Preferred Embodiments

In previous implementations, classes with heavy-volume traffic tended to dominate the bandwidth for a relatively long period of time and cause a high delay jitter

for classes with light traffic volume even if the latter were allocated sufficient bandwidth. Since the traffic volume of some real-time applications, e.g., voice, is relatively low and the bandwidth consumption of such applications is more predictable, it is desirable to separate these applications from the rest of the traffic, which includes many data applications with unpredictable volume and bursty bandwidth consumption. However, while total separation provides security, it also reduces the total utilization of bandwidth. One alternative is to allow voice traffic to borrow bandwidth from data traffic, but not allow data to borrow from voice. In this situation, one wants to reserve sufficient bandwidth for voice and, at the same time, avoid over-engineering in order to increase the bandwidth utilization.

Due to the fact that traffic conditions are dynamic and somewhat unpredictable, it is not possible to find a value for bandwidth allocation that satisfies the desired objectives in all circumstances. The present invention implements a bandwidth sharing hierarchy and a dynamic scheme for setting bandwidth management parameters. Since Internet Protocol (IP) technology is implemented in various access methods, i.e., Cable Plant, fixed wireless, and DSL, and also in the backbone, the present invention has far-reaching applicability in the present and future networks. The present invention provides capabilities for more efficient use of bandwidth and the ability to use the same network for both voice and data applications. Moreover, the present invention provides for integrating voice traffic and data traffic and provides mechanisms for allocation of bandwidth to priority data or voice-over-IP (VOIP) services that ensure that valuable corporate resources are available to critical business applications.

For example, where bandwidth is allocated according to application delay requirements, assume that there are two types of traffic: real-time and non-real-time traffic. There are a predetermined number n of classes, and each type of traffic may have one or more leaf classes: c_1 through c_k are classes of real-time or other critical applications, while the remaining classes c_{k+1} through c_n include non-critical applications. The objectives are twofold:

1. Minimize the delay jitter for real-time applications by reserving sufficient bandwidth.
2. Maximize the overall bandwidth utilization by allowing bandwidth sharing across non- real-time applications.

The above goals are achieved by setting a borrowing permit according to the traffic's delay requirement, i.e., only allowing real-time applications to borrow from non-real-time, but not vice versa. As a result, one needs an extra level in the sharing tree hierarchy as is shown in Figure 1. If c_1 exceeds its allocated bandwidth, it can temporarily borrow from all its parent classes, i.e., RT 104 and Root 102. On the other hand, if $c_{(k+1)}$ exceeds its allocation, it can only borrow from NON-RT 106. Such a sharing hierarchy includes reservation and sharing strategies. However, due to the traffic dynamics, a static allocation that meets the performance objectives in all circumstances has not been available. To guarantee real-time application delay requirements, one needs to allocate sufficient bandwidth to such applications. On the other hand, to maximize the bandwidth utilization, one must maintain the reserved portion of bandwidth as small as possible and maximize the shared portion.

For a better tradeoff between guaranteeing delay and maximizing the utilization, the present invention provides a dynamic scheme that adapts to traffic variations. The present invention utilizes a scheme that is simple enough to be readily implemented - a dynamic setting scheme (DSS) for CBQ. The fundamental concept embedded in DSS is the use of measurable parameters as control triggers. The measurable parameters may be related to performance objectives. For example, queue length may be directly related to delay and delay jitter, which are the main performance measures for real-time traffic. Moreover, borrowing attempts may be used to indicate whether the allocated bandwidth is sufficient. Both queue length and borrowing attempts are easily measured and therefore may be used as control triggers in a DSS scheme. However, other measurable parameters can be used as control triggers in the DSS scheme.

Two examples of DSS are described below wherein queue length and borrowing attempts are used as control triggers. In the first example, where DSS is triggered by borrowing attempts, let A_i be the number of borrowing attempts initiated by class i during an observation window. An "observation window" is a time interval during which the A_i is measured. The objective of DSS is to dynamically adjust the allocated bandwidth for parent classes of real-time or critical traffic according to the number of borrowing attempts made by these classes during the most recent observation window. Since the traffic characteristics are unknown and changing, it is impossible to find an optimal A_i that suits all circumstances. However, by keeping the above state variable within a desired region and allowing a certain degree of fluctuation within the desired region, the performance is kept at a satisfactory level. Therefore, two levels of thresholds are used for A_i , the desired region being designated as the "stable region". The performance is

measured in terms of the delay and delay jitter of real-time classes and the utilization of the root class (which accounts for the total traffic).

The DSS scheme uses the average number of borrowing attempts, A_{i_avg} , to trigger the control actions. The status of the state variable is checked on a periodic basis. If the state variable is in the stable region, no action needs to be taken. If the state variable is outside the stable region, the allocated bandwidth B_i for the real-time class is updated, moving A_{i_avg} back into the stable region. As is known in the art, an exponential smoothing technique is used to calculate the average number of borrowing attempts. Such a smoothing technique avoids too much oscillation due to the effect of overreacting to the system's instantaneous fluctuations. The implication is that as long as the smoothed average values stay inside the stable region, certain incidences are permitted wherein the actual values of the state variable are outside the stable region, either higher than the upper threshold or lower than the lower threshold.

The parameters used in the algorithm are defined as follows. The first set of parameters includes the instantaneous measurement on the state variable and its calculated average value:

- A_i : the number of borrowing attempts during the last measurement window; and
- A_{i_avg} : the average borrowing attempts.

The following set of parameters consists of the upper and lower thresholds on the above state variable which are preset at predetermined desired values:

- $\text{Thr}(A_i)^{\text{lower}}$: the lower threshold for borrowing attempts, e.g. $\text{Thr}(A_i)^{\text{lower}}=2$. One should note that $\text{Thr}(A_i)^{\text{lower}}$ cannot be set to zero.

- $\text{Thr}(A_i)^{\text{upper}}$: the upper threshold for borrowing attempts, e.g. $\text{Thr}(A_i)^{\text{upper}}=10$.

The next parameter is the increment or decrement unit on the allocated bandwidth B_i preset at a predetermined value (where i stands for class i):

- ω_i^{down} : the downward update granularity for allocated bandwidth B_i ;
- ω_i^{up} : the upward update granularity for allocated bandwidth B_i ;

The last two parameters are the upper and lower limits on the allocated bandwidth that are typically selected according to applications being used:

- $\text{Max}(B_i)$: maximum value of allocated bandwidth;
- $\text{Min}(B_i)$: minimum value of allocated bandwidth.

The average state variables may be obtained using the exponential smoothing technique as follows:

$$A_{i_avg} \leftarrow (1-\alpha)*A_{i_avg} + \alpha*A_i ,$$

where the value of α is chosen as a (negative) power of two, i.e., 2^{-n} , $n=0, 1, 2, \dots$, which may be implemented with one shift and two additions. A_{i_avg} is updated every observation window, generally a pre-determined parameter in seconds.

Using the limits and the thresholds, three states are generated for control purposes, as is shown in Figure 3. A_{i_avg} represents a controlled state. As long as the controlled state is outside the stable region, the value of allocated bandwidth B_i will be updated to move the controlled state back to the stable region. Hence, the algorithm for DSS (306) is as follows:

If $A_{i_avg} < \text{Thr}(A_i)^{\text{lower}}$, $B_i = \text{maximum}(B_i - \omega_i^{\text{down}} \text{Min}(B_i))$

Else If $A_{i_avg} > \text{Thr}(A_i)^{\text{upper}}$, $B_i = \text{minimum}(B_i + \omega_i^{\text{up}}, \text{Max}(B_i))$

In the second example, where DSS is triggered by queue length, queue length is used to trigger the DSS so as to control the delay jitter since delay jitter is one of the main performance measures in voice-over-IP applications. Queue length is selected as a control trigger because voice traffic needs to be given strict high priority while traversing the network. Thus, generally voice traffic will not encounter excessive queuing delay inside the network, and, for a given path, the propagation delay is fixed. Hence, the only source for delay jitter for voice traffic will be at the ingress queue. Moreover, where bandwidth is reserved for voice traffic at the bandwidth manager, the queue length Q_i for class i may be related to the upper bound of delay jitter as:

$$\text{Delay_jitter_i} = Q_i / B_i$$

such that, where the desired jitter upper bound Delay_jitter_i is given, then a linear relationship exists between Q_i and B_i (allocated bandwidth) (308).

The parameters used in the second example are defined as follows. The first set of parameters includes the instantaneous measurement on the state variable and its calculated average value:

- Q_i : the queue length;
- Q_{i_avg} : the average queue length.

The following set of parameters consists of the upper and lower thresholds on the above state variable which are preset at predetermined values:

- $\text{Thr}(Q_i)^{\text{lower}}$: the lower threshold for queue length, e.g., $\text{Thr}(Q_i)^{\text{lower}}=2$. One should note that $\text{Thr}(Q_i)^{\text{lower}}$ cannot be set to zero.

- $\text{Thr}(Q_i)^{\text{upper}}$: the upper threshold for queue length, e.g. $\text{Thr}(Q_i)^{\text{upper}}=10$.

As is clear from the explanation above, replacing A_{i_avg} of the above DSS algorithm by Q_{i_avg} yields a DSS triggered by queue length.

Thus, as shown in Figure 2, the present invention may be implemented as a method for dynamically managing allocation of bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ). The steps of the method include: maintaining (202) a minimized reserved portion of bandwidth to minimize delay jitter and maximizing (204) a shared portion of bandwidth to maximize overall bandwidth utilization. Allocation of bandwidth may be based on a sharing tree hierarchical scheme that provides for temporary borrowing of bandwidth by real-time or critical applications from bandwidth of non-real-time or non-critical applications and blocks borrowing of bandwidth by non-real-time or non-critical applications from bandwidth of real-time or critical applications. The DSS may provide for using measurable parameters such as queue length or number of borrowing attempts per a predetermined length of time as control triggers for implementing adjustment of bandwidth allocation.

In another embodiment, as shown in Figure 3, the method of the present invention provides for dynamically managing allocation of bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ), by utilizing the steps of: measuring (302) a predetermined parameter at predetermined observation window times and dynamically adjusting (304) allocated bandwidth for parent classes of real-time or critical traffic by adjusting an average of the predetermined parameter to have a value within a

predetermined stable region. Where the predetermined parameter is a number of borrowing attempts during a measurement window, a maximum bandwidth and a minimum bandwidth for the predetermined stable region may be determined (306) by:

$$\text{If } A_{i_avg} < Thr(A_i)^{lower}, B_i = \text{maximum}(B_i - \omega_i^{down}, \text{Min}(B_i))$$

$$\text{Else If } A_{i_avg} > Thr(A_i)^{upper}, B_i = \text{minimum}(B_i + \omega_i^{up}, \text{Max}(B_i))$$

Where A_i is a number of borrowing attempts during a most recent measurement window and

A_{i_avg} is an average number of borrowing attempts/controlled state;

upper and lower thresholds for the predetermined stable region are preset at predetermined values:

$Thr(A_i)^{lower}$ is a lower threshold for borrowing attempts, where $Thr(A_i)^{lower} > 0$;

$Thr(A_i)^{upper}$ is a upper threshold for borrowing attempts, where $Thr(A_i)^{upper} > Thr(A_i)^{lower}$;

increment and decrement units ω_i^{down} and ω_i^{up} , which denote the update granularity on allocated bandwidth B_i , are preset at predetermined values;

$Max(B_i)$ is a maximum value of allocated bandwidth;

$Min(B_i)$ is a minimum value of allocated bandwidth; and

exponential smoothing technique is used as follows,

$$A_{i_avg} \leftarrow (1-\alpha) * A_{i_avg} + \alpha * A_i,$$

where a value of α is preselected as a negative power of two and A_{i_avg} is updated every observation window, a pre-determined parameter in seconds.

Where the predetermined parameter is a queue length, a lower threshold and an upper threshold for queue length for the predetermined stable region may be determined (308)

by:

$$\text{If } Q_{i_avg} < Thr(Q_i)^{lower}, B_i = \text{maximum}(B_i - \omega_i^{down}, \text{Min}(B_i))$$

$$\text{Else If } Q_{i_avg} > Thr(Q_i)^{upper}, B_i = \text{minimum}(B_i + \omega_i^{up}, \text{Max}(B_i)),$$

Q_i is an instantaneous measurement of queue length;

Q_{i_avg} is a calculated average value for an average queue length;

upper and lower thresholds are preset at predetermined values:

$Thr(Q_i)^{lower}$ is a lower threshold for queue length, where $Thr(Q_i)^{lower} > 0$; and

$Thr(Q_i)^{upper}$ is an upper threshold for queue length where $Thr(Q_i)^{upper} > Thr(Q_i)^{lower}$.

A queue size for class i , which is also an upper bound for a queue length Q_i , is related to an upper bound on a delay jitter as:

$$\text{Delay_jitter_}i = \max Q_i / B_i$$

Hence, if a jitter upper bound $\text{Delay_jitter_}i$ is preselected, then a linear relationship exists between $\max Q_i$ and B_i , the allocated bandwidth.

In one embodiment, as shown in Figure 3, a computer-readable medium 310 having computer-executable instructions may be utilized for dynamically managing allocation of bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ), wherein the computer-executable instructions comprise the steps of: measuring (302) a predetermined parameter at predetermined observation window times and dynamically adjusting (304) allocated bandwidth for parent classes of

real-time or critical traffic by adjusting an average of the predetermined parameter to have a value within a predetermined stable region. The steps of the computer-executable instructions may also be implemented as described above for the method.

Figure 4 is a block diagram showing one embodiment of a device (406) for dynamically managing allocation of bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ). The device (406) typically includes a parameter measuring unit (402) and a bandwidth sharing determining unit (404). The parameter measuring unit (402) is coupled to a bandwidth sharing determining unit (404), and measures a predetermined parameter at predetermined observation window times. The bandwidth sharing determining unit (404) is coupled to the parameter measuring unit (402), and dynamically adjusts allocated bandwidth for parent classes of real-time or critical traffic by adjusting an average of the predetermined parameter to have a value within a predetermined stable region. Typically, the DSS provides for using measurable parameters such as queue length or number of borrowing attempts per a predetermined length of time or window of time as control triggers for implementing adjustment of bandwidth allocation. Where the predetermined parameter is a number of borrowing attempts during a measurement window, a maximum bandwidth and a minimum bandwidth for the predetermined stable region may be determined by:

$$\text{If } A_{i_avg} < Thr(A_i)^{lower}, B_i = \text{maximum}(B_i - \omega_i^{down}, Min(B_i))$$

$$\text{Else If } A_{i_avg} > Thr(A_i)^{upper}, B_i = \text{minimum}(B_i + \omega_i^{up}, Max(B_i))$$

as described more fully above. Where the predetermined parameter is a queue length, and a lower threshold and an upper threshold for queue length for the predetermined stable region may be determined by:

If $Q_{i_avg} < Thr(Q)^{lower}$, $B_i = \text{maximum}(B_i - \omega_i^{down}, \text{Min}(B_i))$

Else If $Q_{i_avg} > Thr(Q)^{upper}$, $B_i = \text{minimum}(B_i + \omega_i^{up}, \text{Max}(B_i))$,

as described more fully above. The dynamically adjusted allocated bandwidth for real-time or critical applications and non-real-time or non-critical applications is sent by the bandwidth sharing determining unit (404) to a bandwidth manager or traffic shaper (408), which then sends information on the real-time or critical applications and non-real-time or non-critical applications seeking to use the bandwidth to the parameter measuring unit (402).

Although the present invention has been described in relation to particular preferred embodiments thereof, many variations, equivalents, modifications and other uses will become apparent to those skilled in the art. It is preferred, therefore, that the present invention be limited not by the specific disclosure herein, but only by the appended claims.

What is claimed is:

CLAIMS

1. A method for dynamically managing allocation of bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ), comprising the steps of:

maintaining a minimized reserved portion of bandwidth to minimize delay jitter; and
maximizing a shared portion of bandwidth to maximize overall bandwidth utilization.

2. The method of claim 1 wherein allocation of bandwidth is based on a sharing tree hierarchical scheme that provides for temporary borrowing of bandwidth by real-time applications from bandwidth of non-real-time applications and blocks borrowing of bandwidth by non-real-time applications from bandwidth of real-time applications.

3. The method of claim 1 wherein the DSS provides for using measurable parameters as control triggers for implementing adjustment of bandwidth allocation.

4. The method of claim 3 wherein the measurable parameters include at least one of: queue length and number of borrowing attempts per a predetermined length of time.

5. A method for dynamically managing allocation of bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ), comprising the steps of:

measuring a predetermined parameter at predetermined observation window times; and

dynamically adjusting allocated bandwidth for parent classes of real-time traffic by adjusting an average of the predetermined parameter to have a value within a predetermined stable region.

6. The method of claim 5 wherein dynamically adjusting allocated bandwidth is based on a sharing tree hierarchical scheme that provides for temporary borrowing of bandwidth by real-time applications from bandwidth of non-real-time applications and blocks borrowing of bandwidth by non-real-time applications from bandwidth of real-time applications.
7. The method of claim 5 wherein the predetermined parameter measured is one of: queue length and number of borrowing attempts during a predetermined measurement window.
8. The method of claim 5, where the predetermined parameter is a number of borrowing attempts during a measurement window, and a maximum bandwidth and a minimum bandwidth for the predetermined stable region are determined by:

$$\text{If } A_{i_avg} < Thr(A_i)^{lower}, B_i = \text{maximum}(B_i - \omega_i^{down}, \text{Min}(B_i))$$

$$\text{Else If } A_{i_avg} > Thr(A_i)^{upper}, B_i = \text{minimum}(B_i + \omega_i^{up}, \text{Max}(B_i))$$

Where A_i is a number of borrowing attempts during a most recent measurement window and

A_{i_avg} is an average number of borrowing attempts/controlled state;

upper and lower thresholds for the predetermined stable region are preset at predetermined values:

$Thr(A_i)^{lower}$ is a lower threshold for borrowing attempts, where

$$Thr(A_i)^{lower} > 0;$$

$Thr(A_i)^{upper}$ is an upper threshold for borrowing attempts, where $Thr(A_i)^{upper} > Thr(A_i)^{lower}$;

increment and decrement units ω_i^{down} and ω_i^{up} , which denote an update granularity on allocated bandwidth B_i , are preset at predetermined values;

$Max(B_i)$ is a maximum value of allocated bandwidth;

$Min(B_i)$ is a minimum value of allocated bandwidth; and

exponential smoothing technique is used as follows,

$$A_{i_avg} \leftarrow (1-\alpha)*A_{i_avg} + \alpha*A_i,$$

where a value of α is preselected as a negative power of two and A_{i_avg} is updated every observation window, a pre-determined parameter in seconds.

9. The method of claim 5, where the predetermined parameter is a queue length, and a lower threshold and an upper threshold for queue length for the predetermined stable region are determined by:

If $Q_{i_avg} < Thr(Q_i)^{lower}$, $B_i = \text{maximum}(B_i - \omega_i^{down}, Min(B_i))$

Else If $Q_{i_avg} > Thr(Q_i)^{upper}$, $B_i = \text{minimum}(B_i + \omega_i^{up}, Max(B_i))$,

Q_i is an instantaneous measurement of queue length;

Q_{i_avg} is a calculated average value for an average queue length;

upper and lower thresholds are preset at predetermined values:

$Thr(Q_i)^{lower}$ is a lower threshold for queue length, where $Thr(Q_i)^{lower} > 0$;

$Thr(Q_i)^{upper}$ is an upper threshold for queue length where $Thr(Q_i)^{upper} >$

$Thr(Q_i)^{lower}$; and

a queue size for class i , which is also an upper bound for a queue length Q_i , is related to an upper bound on a delay jitter as:

$$\text{Delay_jitter_}i = \max Q_i / B_i$$

wherein, if a jitter upper bound $\text{Delay_jitter_}i$ is preselected, then a linear relationship exists between $\max Q_i$ and B_i , an allocated bandwidth.

10. A computer-readable medium having computer-executable instructions for dynamically managing allocation of bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ), wherein the computer-executable instructions comprise the steps of:

measuring a predetermined parameter at predetermined observation window times; and
dynamically adjusting allocated bandwidth for parent classes of real-time traffic by adjusting an average of the predetermined parameter to have a value within a predetermined stable region.

11. The computer-readable medium of claim 10 wherein dynamically adjusting allocated bandwidth is based on a sharing tree hierarchical scheme that provides for temporary borrowing of bandwidth by real-time applications from bandwidth of non-real-time applications and blocks borrowing of bandwidth by non-real-time applications from bandwidth of real-time applications.

12. The computer-readable medium of claim 10 wherein the predetermined parameter measured is one of: queue length and number of borrowing attempts during a predetermined measurement window.

13. The computer-readable medium of claim 10, where the predetermined parameter is a number of borrowing attempts during a measurement window, and a maximum bandwidth and a minimum bandwidth for the predetermined stable region are determined by:

$$\text{If } A_{i_avg} < Thr(A_i)^{lower}, B_i = \text{maximum}(B_i - \omega_i^{down}, \text{Min}(B_i))$$

$$\text{Else If } A_{i_avg} > Thr(A_i)^{upper}, B_i = \text{minimum}(B_i + \omega_i^{up}, \text{Max}(B_i))$$

Where A_i is a number of borrowing attempts during a most recent measurement window and

A_{i_avg} is an average number of borrowing attempts/controlled state;

upper and lower thresholds for the predetermined stable region are preset at predetermined values:

$Thr(A_i)^{lower}$ is a lower threshold for borrowing attempts, where

$$Thr(A_i)^{lower} > 0;$$

$Thr(A_i)^{upper}$ is an upper threshold for borrowing attempts, where

$$Thr(A_i)^{upper} > Thr(A_i)^{lower};$$

increment and decrement units ω_i^{down} and ω_i^{up} , which denote the update granularity on allocated bandwidth B_i , are preset at predetermined values;

$Max(B_i)$ is a maximum value of allocated bandwidth;

$Min(B_i)$ is a minimum value of allocated bandwidth; and

exponential smoothing technique is used as follows,

$$A_{i_avg} \leftarrow (1-\alpha)*A_{i_avg} + \alpha*A_i,$$

where a value of α is preselected as a negative power of two and A_{i_avg} is updated every observation window, a pre-determined parameter in seconds.

14. The computer-readable medium of claim 10, where the predetermined parameter is a queue length, and a lower threshold and an upper threshold for queue length for the predetermined stable region are determined by:

$$\text{If } Q_{i_avg} < Thr(Q_i)^{lower}, B_i = \text{maximum}(B_i - \omega_i^{down}, \text{Min}(B_i))$$

$$\text{Else If } Q_{i_avg} > Thr(Q_i)^{upper}, B_i = \text{minimum}(B_i + \omega_i^{up}, \text{Max}(B_i)),$$

Q_i is an instantaneous measurement of queue length;

Q_{i_avg} is a calculated average value for an average queue length;

upper and lower thresholds are preset at predetermined values:

$Thr(Q_i)^{lower}$ is a lower threshold for queue length, where $Thr(Q_i)^{lower} > 0$;

$Thr(Q_i)^{upper}$ is an upper threshold for queue length where $Thr(Q_i)^{upper} >$

$Thr(Q_i)^{lower}$; and

a queue size for class i , which is also an upper bound for a queue length Q_i , is related to an upper bound on a delay jitter as:

$$\text{Delay_jitter_}i = \text{max}Q_i / B_i$$

wherein, if a jitter upper bound $\text{Delay_jitter_}i$ is preselected, then a linear relationship exists between $\text{max}Q_i$ and B_i , an allocated bandwidth.

15. A device for dynamically managing allocation of bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ), comprising:

a parameter measuring unit, coupled to a bandwidth sharing determining unit, for measuring a predetermined parameter at predetermined observation window times; and

the bandwidth sharing determining unit, coupled to the parameter measuring unit, for dynamically adjusting allocated bandwidth for parent classes of real-time traffic by adjusting an average of the predetermined parameter to have a value within a predetermined stable region.

16. The device of claim 15 wherein the DSS for bandwidth allocation is based on a sharing tree hierarchical scheme that provides for temporary borrowing of bandwidth by real-time applications from bandwidth of non-real-time applications and blocks borrowing of bandwidth by non-real-time applications from bandwidth of real-time applications.

17. The device of claim 15 wherein the DSS provides for using measurable parameters as control triggers for implementing adjustment of bandwidth allocation.

18. The device of claim 15 wherein the measurable parameters include at least one of: queue length and number of borrowing attempts per a predetermined length of time.

19. The device of claim 15, where the predetermined parameter is a number of borrowing attempts during a measurement window, and a maximum bandwidth and a minimum bandwidth for the predetermined stable region are determined by:

$$\begin{aligned} \text{If } A_{i_avg} < Thr(A_i)^{lower}, B_i &= \text{maximum}(B_i - \omega_i^{down}, Min(B_i)) \\ \text{Else If } A_{i_avg} > Thr(A_i)^{upper}, B_i &= \text{minimum}(B_i + \omega_i^{up}, Max(B_i)) \end{aligned}$$

Where A_i is a number of borrowing attempts during a most recent measurement window and

A_{i_avg} is an average number of borrowing attempts/controlled state;

upper and lower thresholds for the predetermined stable region are preset at predetermined values:

$Thr(A_i)^{lower}$ is a lower threshold for borrowing attempts, where $Thr(A_i)^{lower} > 0$;

$Thr(A_i)^{upper}$ is an upper threshold for borrowing attempts, where $Thr(A_i)^{upper} > Thr(A_i)^{lower}$;

increment and decrement units ω_i^{down} and ω_i^{up} , which denote the update granularity on allocated bandwidth B_i , are preset at predetermined values;

$Max(B_i)$ is a maximum value of allocated bandwidth;

$Min(B_i)$ is a minimum value of allocated bandwidth; and

exponential smoothing technique is used as follows,

$$A_{i_avg} \leftarrow (1-\alpha)*A_{i_avg} + \alpha*A_i,$$

where a value of α is preselected as a negative power of two and A_{i_avg} is updated every observation window, a pre-determined parameter in seconds.

20. The device of claim 15, where the predetermined parameter is a queue length, and a lower threshold and an upper threshold for queue length for the predetermined stable region are determined by:

$$\text{If } Q_{i_avg} < Thr(Q_i)^{lower}, B_i = \text{maximum}(B_i - \omega_i^{down}, Min(B_i))$$

$$\text{Else If } Q_{i_avg} > Thr(Q_i)^{upper}, B_i = \text{minimum}(B_i + \omega_i^{up}, Max(B_i)),$$

Q_i is an instantaneous measurement of queue length;

Q_{i_avg} is a calculated average value for an average queue length;

upper and lower thresholds are preset at predetermined values:

$Thr(Q_i)^{lower}$ is a lower threshold for queue length, where $Thr(Q_i)^{lower} > 0$;

$Thr(Q_i)^{upper}$ is an upper threshold for queue length where $Thr(Q_i)^{upper} >$

$Thr(Q_i)^{lower}$; and

a queue size for class i , which is also an upper bound for a queue length Q_i , is related to an upper bound on a delay jitter as:

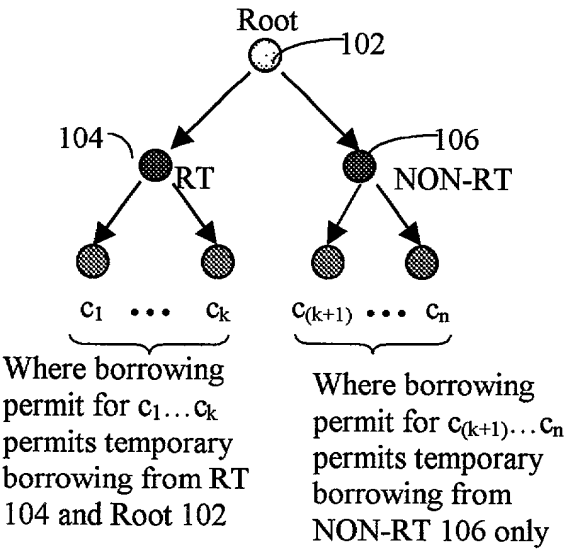
$$Delay_jitter_i = \max Q_i / B_i$$

wherein, if a jitter upper bound $Delay_jitter_i$ is preselected, then a linear relationship exists between $\max Q_i$ and B_i , an allocated bandwidth.

ABSTRACT OF THE DISCLOSURE

The present invention provides a method, computer-readable medium and device for dynamically managing allocation of bandwidth in a packet network using a Dynamic Setting Scheme (DSS) for Class Based Queuing (CBQ). The method includes the steps of maintaining a minimized reserved portion of bandwidth to minimize delay jitter and maximizing a shared portion of bandwidth to maximize overall bandwidth utilization. Allocation of bandwidth may be based on a sharing tree hierarchical scheme that provides for temporary borrowing of bandwidth by real-time applications from bandwidth of non-real-time applications and blocks borrowing of bandwidth by non-real-time applications from bandwidth of real-time applications. DSS typically provides for using measurable parameters, such as queue length and number of borrowing attempts per a predetermined length of time/observation window, as control triggers for implementing adjustment of bandwidth allocation. In one embodiment, the steps include measuring a predetermined parameter at predetermined observation window times and dynamically adjusting allocated bandwidth for parent classes of real-time traffic by adjusting an average of the predetermined parameter to have a value within a predetermined stable region.

Figure 1



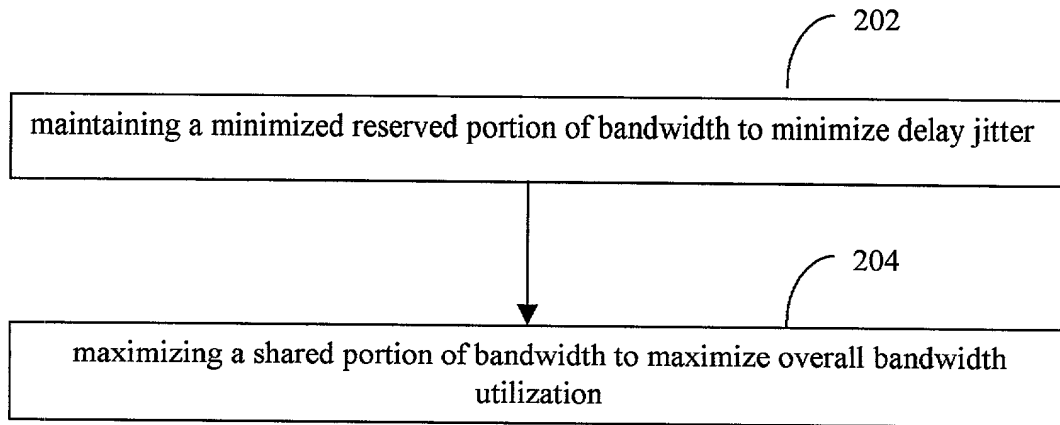


Figure 2

Computer-readable medium/method 310

measuring a predetermined parameter at predetermined observation window times

dynamically adjusting allocated bandwidth for parent classes of real-time traffic by adjusting an average of the predetermined parameter to have a value within a predetermined stable region

Where the predetermined parameter is a number of borrowing attempts during a measurement window, a maximum bandwidth and a minimum bandwidth for the predetermined stable region is determined by:

If $A_{i_avg} < Thr(A_i)^{lower}$, $B_i = \text{maximum}(B_i - \omega_i, \text{Min}(B_i))$

Else If $A_{i_avg} > Thr(A_i)^{upper}$, $B_i = \text{minimum}(B_i + \omega_i, \text{Max}(B_i))$

Where exponential smoothing includes:

$A_{i_avg} \leftarrow (1-\alpha) * A_{i_avg} + \alpha * A_i$, where a value of α is preselected as a negative power of two and A_{i_avg} is updated every observation window, a pre-determined parameter in seconds and

the queue length Q_i for class i may be related to the upper bound of delay jitter as:

$$\text{Delay_jitter_i} = Q_i / B_i$$

such that, where the desired jitter upper bound Delay_jitter_i is given, then a linear relationship exists between Q_i and B_i (allocated bandwidth)

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Where the predetermined parameter is a queue length, a lower threshold and an upper threshold for queue length for the predetermined stable region may be determined by :

If $Q_{i_avg} < Thr(Q_i)^{lower}$, $B_i = \text{maximum}(B_i - \omega_i, \text{Min}(B_i))$

Else If $Q_{i_avg} > Thr(Q_i)^{upper}$, $B_i = \text{minimum}(B_i + \omega_i, \text{Max}(B_i))$,

and $\text{Delay_jitter_i} = \text{max}Q_i / B_i$

wherein, if a jitter upper bound Delay_jitter_i is preselected, then a linear relationship exists between $\text{max}Q_i$ and B_i , an allocated bandwidth.

Fig.
3

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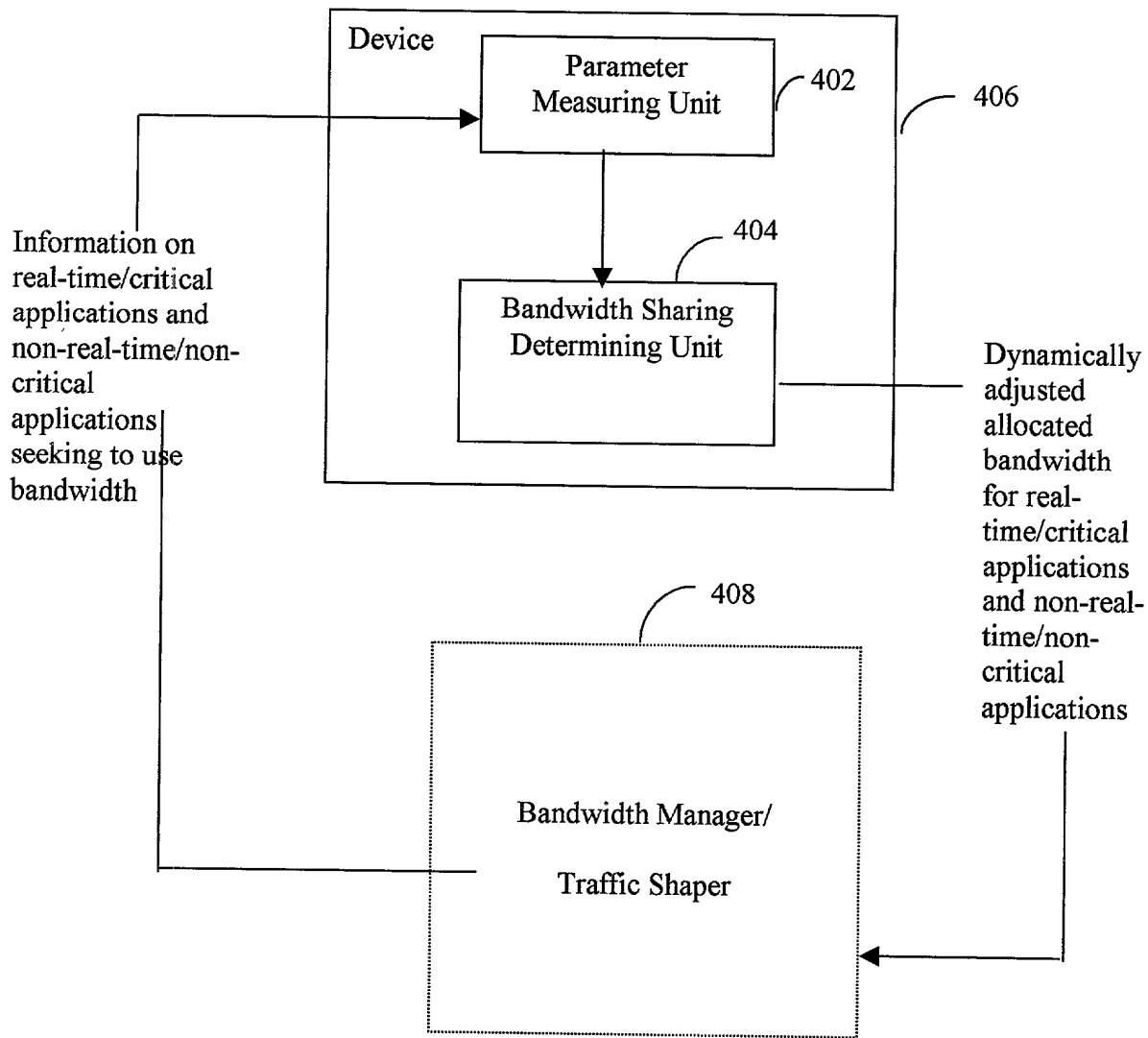


Figure 4

IN THE UNITED STATES
PATENT AND TRADEMARK OFFICE

Declaration and Power of Attorney

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am an original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled **Method And Device For Efficient Bandwidth Management**, the specification of which is attached hereto.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by an amendment, if any, specifically referred to in this oath or declaration.

I acknowledge the duty to disclose all information known to me which is material to patentability as defined in Title 37, Code of Federal Regulations, 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, 119(a-d) or 365(a-b) of PCT or foreign application(s) for patent or inventors' certificate listed below or priority benefits under 119(e) of any United States provisional application(s) listed below and have also identified below any foreign application for patent or inventors' certificate having a filing date before that of the application on which priority is claimed:

None

I hereby claim the benefit under Title 35, United States Code, 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, 112, we acknowledge the duty to disclose all information known to us to be material to patentability as defined in Title 37, Code of Federal Regulations, 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

None

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

I hereby appoint the following attorney(s) with full power of substitution and revocation, to prosecute said application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent and Trademark Office connected therewith:

Samuel H. Dworetsky	(Reg. No. 27873)	Benjamin S. Lee	(Reg. No. 42787)
Thomas A. Restaino	(Reg. No. 33444)	Robert B. Levy	(Reg. No. 28234)
Robert T. Canavan	(Reg. No. 37592)	Susan E. McGahan	(Reg. No. 35948)
Michele L. Conover	(Reg. No. 34962)	Gary H. Monka	(Reg. No. 35290)
Cedric G. DeLaCruz	(Reg. No. 36498)	Jeffrey M. Navon	(Reg. No. 32711)
Rohini K. Garg	(Reg. No. 45272)	Alfred G. Steinmetz	(Reg. No. 22971)
Gregory J. Gorrie	(Reg. No. 36530)	Christine Szwerc	(Reg. No. 43177)
Thomas M. Isaacson	(Reg. No. 44166)		

I also appoint Thomas H. Jackson (Reg. No. 29808), Frederic M. Meeker (Reg. No. 35282), Joseph P. Krause (Reg. No. 32578) and Darleen J. Stockley (Reg. No. 34257) of Banner & Witcoff as associate attorney, with full power to prosecute said application, to make alterations and amendments therein, and to transact all business in the Patent and Trademark Office connected therewith.

Please address all correspondence to Mr. S. H. Dworetsky, AT&T Corp., P.O. Box 4110, Middletown, New Jersey 07748. Telephone calls should be made to Susan E. McGahan at 908-221-5776.

Full name of 1st joint inventor: Yonatan Aharon Levy


Inventor's signature Yonatan Aharon Levy Date 11/27/00

Residence: Manalapan, Monmouth County, New Jersey

Citizenship: United States of America

Post Office Address: 1 Grant Road
Manalapan, New Jersey 07726

Full name of 2nd joint inventor: Xiaowen Mang

Inventor's signature  Date 11/13/00

Residence: Manalapan, Monmouth County, New Jersey

Citizenship: People's Republic of China

Post Office Address: 12 Sutton Drive
Manalapan, New Jersey 07726

Full name of 3rd joint inventor: Kamlesh T. Tewani

Inventor's signature

Date

11/13/2000

Residence: Freehold, Monmouth County, New Jersey

Citizenship: United States of America

Post Office Address:

37 Jefferson Court
Freehold, New Jersey

07728